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OPTICAL AND MECHANICAL CHARACTERISTICS OF FIBERS MADE OF ARSENIC CHALCOGENIDES

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Optical and mechanical characteristics of optical fibers made of high-purity chalcogenide glasses of As-S, As-S-Se, As-Se and Ge-As-Se systems, intended for operation in the middle IR, are given. The fibers from As-S glass will be useful for transmission of IR-radiation in the 1-7 microns spectral region, the fibers on the basis of As-Se and Ge-As-Se glass systems - in the 2-12 microns region. The multimode fibers from arsenic-sulfide and arsenic-selenide glasses have the minimum optical losses equal to 23 ± 8 dB/km and 79 ±10 dB/km at 2.4 and 4.5 microns, respectively. The average bending strength of As-S glass fibers (with diameter of 350-400 microns) is from 1.0 up to 1.2 GPa, and from 0.4 up to 0.8 GPa for the fibers made of As-Se and Ge-As-Se glasses. The single-mode fibers from As-S glasses have the minimum optical losses from 200 up to 400 dB/km in the 1.3 - 3 microns wavelength region. The choice of the glasses compositions for the fiber core and reflecting cladding which provides the given numerical aperture and the mode parameters in the required spectral region is discussed. The features of modal distribution of radiation along the arsenic-sulfide fiber length were explored.

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1. Introduction

For various practical applications the fibers based on high purity arsenic–sulfide and arsenic-selenide glasses distinguished in structure, waveguide characteristics, in a level of optical losses in the required spectral range, in mechanical strength, aperture and other parameters are required. These are multimode fibers with a reflecting cladding from relevant chalcogenide glass, fibers with a reflecting polymeric cladding, fibers without a reflecting cladding, and also single-mode fibers.

The number of checked parameters for the fibers reaches ten. It is a diameter of a core of a fiber, ratio of diameters of a core and reflecting cladding, concentricity of an arrangement of a core and cladding, concentricity of a secondary coat, the numerical aperture, mechanical strength, the minimum permissible radius of bending, continuous length of a fiber, level of optical losses in the required spectral range etc. At development of installations for the fiber drawing from high purity chalcogenide the main problem was the possibility to control all the fiber parameters.

The fibers from high purity sulfide- and arsenic-selenide glasses were made by drawing from ordinary and double crucible.

A primary coating from fluoroplastic F-42 was applied on a fiber during drawing. A fiber was passed through an applicator with a solution of F-42 in methyl-ethyl kethone and further through a pipe heater, where the solvent was evaporated.

A secondary protective coating was applied by drawing the fiber with a primary coating through an applicator with PVC plastizole with the subsequent thermal solidification in the furnace. This process carried out as an additional independent stage after the drawing of a fiber.

The total mass of a glass loaded into double crucibles was from 400 up to 800 grams, that allowed to draw from 500 up to 1000 m of optical fibre with its diameter from 500 up to 300 microns.

To form the optical fiber structure it is necessary to ensure a relative difference of refractive index of the core and the cladding materials of a fiber. Depending on this difference value the numerical aperture of a fiber NA changes:

$$NA = \sin\theta = (n^2_{core} - n^2_{clad})^{1/2} \quad (1)$$

where NA is the numerical aperture of a fiber, θ is the permissible half-angle of input of radiation into a fiber, n_{core} is the refractive index of a core material, n_{clad} is the refractive index of a cladding material.

The necessary ratio of these parameters is provided by the relevant difference in composition of glasses.

2. Fibers based on a high purity arsenic-sulfide glasses

The core glass of multimode fibers had composition from $As_{40}S_{60}$ up to $As_{38}S_{62}$. Compositions for the core and cladding were selected in view of the required NA. For cladding a glass with a smaller content of arsenic was taken in comparison with glass of the core.

The expression for calculation of a numerical aperture of fibers from arsenic-sulfide glasses was derived on the basis of [1]:

$$NA = \{(0.00018(x^2_{core} - x^2_{clad}) + 0.05131(x_{core} + x_{clad}) + 7.32986\}^{1/2} \quad (2)$$

where x_{core} and x_{clad} is the content of arsenic, at. %, in the glass of core and cladding, respectively.

Both low-aperture fibers with a ratio of compositions of a core and cladding not exceeding 1 at. %, and high-aperture fibers, with a ratio of compositions up to 5 at. % were made. The compositions of glasses of core and cladding for a single-mode fiber were selected so that the well-known expression describing a single-mode condition of a fiber was satisfied:

$$(2\pi a/\lambda)(n^2_{core} - n^2_{clad})^{1/2} \leq 2.4 \quad (3)$$

where a is the radius of a core of a fiber, λ is the wavelength, n_{core} and n_{clad} is the refractive index of a core and cladding material of a fiber, respectively.

For values of a core diameter in the interval from 5 up to 6 microns, the difference of refractive indices of a core and cladding materials should be from 0.2 to 0.3 %. It follows from expression (2), that the glass of a cladding should differ from a glass of a core with the contents of arsenic not more than 0.4 - 0.6 at. %. For the $As_{40}S_{60}$ core material composition the glass cladding of a single-mode fiber had the composition of $As_{39.5}S_{60.5}$.

At manufacturing a single-mode fiber two procedures of fiber drawing was used. At first by the method of a double crucible the two-layer fibers with a diameter from 0.8 up to 1 mm with a ratio of diameters of a core and cladding 1:5 were obtained. Then from a cladding glass the tubes with a diameter of 8 mm with ratio of inner and outer diameters equal to 1:10 were prepared. A piece of a two-layer fiber inserted into this tube and the obtained "rod-in-tube" preform was drawn into a single-mode fiber with a diameter of a core equal to 5 - 8 microns, with the total diameter equal to 250 microns.

The second procedure is based on a direct drawing of a fiber from a double crucible. The microphoto of a cross-section of a single-mode fiber made in such a way, is given in Fig. 1.

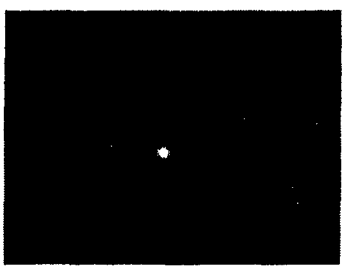

Fig. 1. A microphoto of a cross-section of a single-mode fiber. A diameter of a core is 6 microns, diameter of a cladding - 125 microns.

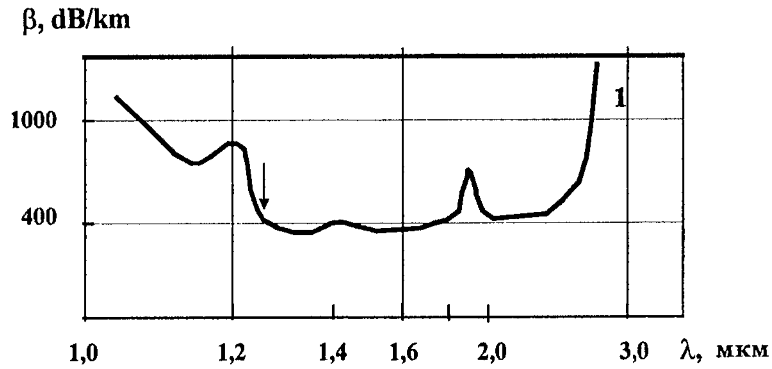

Fig. 2. Spectral dependence of the total optical losses in a single-mode fiber made of high-purity arsenic-sulfide glass with $As_{40}S_{60}$ core [2], the arrow shows the cutoff wavelength .

The spectrum of total optical losses of a single-mode fiber, made on the first procedure, is given in Fig.2. A spectrum of total optical losses of a multi-mode fiber from glasses of the same composition is given in Fig. 3.

From Figs. 2 and 3 it can be seen that the minimum optical losses in a single-mode fiber are much higher than in a multi-mode fiber. Higher losses in a single-mode fiber can be explained by the imperfection of core – cladding boundary in a single-mode fiber. Now optical losses in single-mode fibers from a arsenic-sulfide glass were reduced by us to 250-300 dB/km.

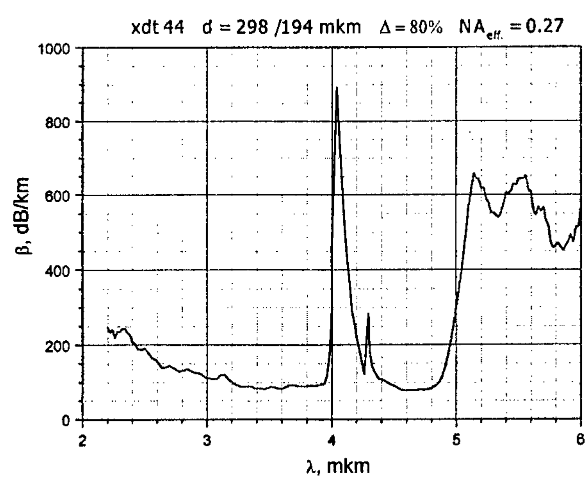

Fig. 3. Spectral dependence of the total optical losses in a multi-mode fiber made of high purity arsenic-sulfide glass with $As_{40}S_{60}$ core.

In Table 1 the main parameters are given for the multi-mode and single-mode fibers based on high purity arsenic-sulfide glass [3].

Table 1. Main parameters of the optical fibres from high-purity As-S glasses.

Type of optical fibre	Continious length	Core/Clad diameter ratio/(μm)	NA	Minimum loss at 2,2 - 4 μm/ (dB/km)	Core concentricity/ (%)	Bending strength/(GPa)	Notes
Multimode	Up to hundreds of meters	300/400, 130/250	0.13 - 0,4	20 - 100	≥ 85	0,8-1,2	Intensity of OH<0.3 dB/m SH < 1 dB/m
Single-mode	tens of meters	8/200 6/125	Not measured	400	≥ 85	0,4-0,6	Cut-off wavelength : 1.1 - 1.5 μm

3. Study of numerical aperture (NA) of the fibers made of arsenic - sulfide glasses

In various instruments and devices the fibers with length from 1 up to 20 m are used. The choice of a fiber for specific application requires a detailed knowledge of its optical parameters.

In many cases the fibers are used which length is insufficient for achievement of a stationary modal distribution at an arbitrary distribution of a radiation power at the input of a fiber. An information on the values of a numerical aperture for short pieces of chalcogenide fibers is scarce. We investigated behavior of a numerical aperture of infrared fibers made of As_2S_3 glass at unsteady modal distribution depending on the aperture of exciting radiation.

Numerical aperture of fibers was determined by the far-field method. The method is based on measurement of a spatial distribution of a radiated power coming out of a fiber, at a distance from an output fiber end being much greater than diameter of a fiber.

For carrying out an experiment the two-layer multi-mode fibers with the diameter of a core of 300 microns and thickness of a reflecting cladding 50 microns were used. Glasses of compositions $As_{40}S_{60}$ and As_{39} S_{61} were respectively used as a material of a core and the claddings, with a difference of refractive index equaled to 0.013. Total optical losses at 5.5 microns wavelength were 800 dB/km. The end faces of fibers were prepared by the method a notch--breakage with the subsequent quality control of the cut with a microscope.

In Figs. 4 and 5 the results of measurement of the aperture of a fiber NA_{eff} are submitted depending on the aperture of excited radiation NA_{in} and length of a fiber. It follows from Fig. 4 that NA_{eff} for fibers with length 1 m is much more than with length of 15 m. At increase of a fiber length the NA_{eff} decreases and tends to the calculated value. The calculated curve is obtained from expression (1) in which the values of refractive index of a core glass are used.

The dependences NA_{eff}, submitted in Figs. 4 and 5, are explained as follows: in a multi-mode fiber with a step-by-step profile of refractive index each spreading mode has a reduction factor, and the modes of the highest order are spreading at angles, close to ultimate, and have optical losses by tens times higher than modes of the lowest order. In case when the radiation is inlet at large angles into short fibers, the modes of the highest order are not completely damp and give the contribution into value NA_{eff}. At a radiation transmission along a fiber the differential losses are partially compensated by modal conversion. When total compensation is achieved, each mode has identical attenuation and the transmission goes at a stationary modal distribution at which the attenuation in a fiber is an exponential function of its length. The measure of achievement of a stationary modal distribution is an invariance of a directional diagram of radiation, coming out of fiber end, in the far-field region under different conditions of excitation. It can be seen from Fig. 5 that it is reached at fiber lengths more than 15 m.

For study of the contribution of the highest order modes into final value of a numerical aperture, the NA measurements of the fiber with an immersion coating at reflecting cladding were carried out. As an immersion medium a chalcogenide glass was used with refractive index slightly exceeding the refractive index of a cladding glass. An immersion coating was applied on a section of a fiber with length 5 cm at 15 cm from an input fiber end face. It was found that the stationary modal distribution is reached at more short lengths of a fiber, about 3 m.

The numerical aperture of a fiber with a primary metal coating was determined. On a fiber glass reflective cladding the layer of indium with thickness 10 microns was applied. The stationary modal distribution for a fiber with a metal coating was achieved at lengths less than 1 m (Fig. 6, curve 3). The metal coating assists the decay of modes of the highest order in a reflecting cladding along the whole fiber length, excluding their influence on NA_{eff}. The refractive index of indium is higher than refractive index of chalcogenide glass ($n_{In} = 10$, $n_{ch.glass} = 2.4$), therefore the total internal reflection at the "reflecting cladding - indium coating" boundary is absent, and the radiation along the cladding is spreading only due to mirror reflection with a coefficient $R \leq 0.97$. At angle close to the critical and the value $R = 0.97$ lengths, on which the radiation intensity in a cladding will decrease by 2 orders, is equal to approximately 10 cm.

As a result of the investigation the lengths of stationary modal distribution for fibers with primary coatings from fluoroplastic F-42, from metal indium and for a fiber with immersion at the

input end face were determined. At unsteady modal distribution the value of a numerical aperture of a fiber depends on the aperture of input radiation, length of a fiber and of a kind of a primary coating. The results obtained are useful at selecting the optimal length of fibers at measurement of its optical losses by a standard double point method and at a selection of the type and parameters of fibers at their practical application.

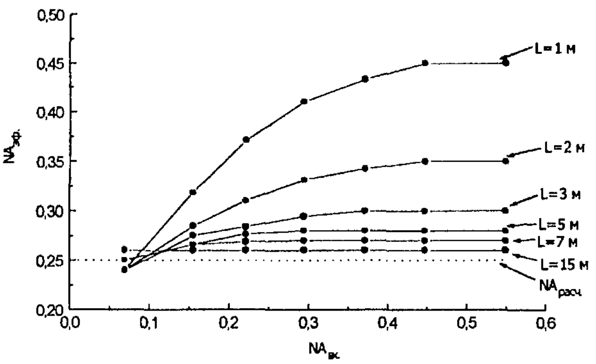

Fig. 4. Dependence of the effective numerical aperture of a fiber NA_{eff} on a numerical aperture of exciting radiation NA_{in}. A primary coating- fluoroplastic F-42, thickness 10 microns.

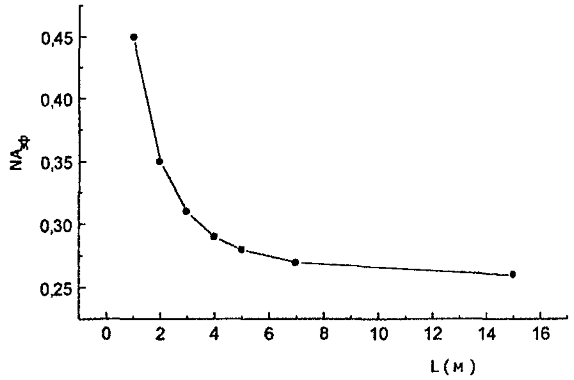

Fig. 5. Numerical aperture NA_{eff} of a fiber versus fiber length for NA_{in} = 0.55. A primary coating- fluoroplastic F-42, thickness 10 microns.

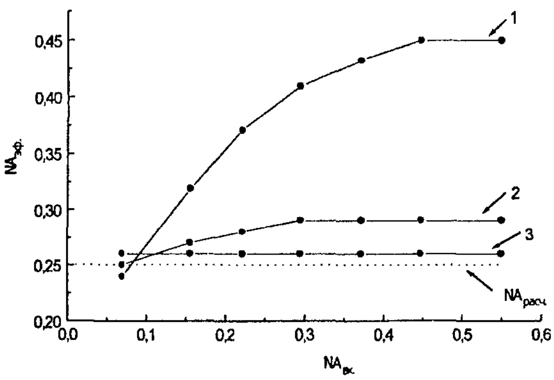

Fig. 6. Numerical aperture of a fiber NA_{eff} versus numerical aperture NA_{in} of exciting radiation for 1 meter length: 1 is with fluoroplastic F-42 coating, 2 is with glass immersion, 3 is with metallic indium coating.

4. Multi-core fibers based on arsenic-sulfide glass

For coupling with IR-radiation detectors, with systems of thermal imaging and IR-introscopes, the flexible fiber bundles consisting of a number of regularly located fibers of a small diameter are required at present time. Such multi-core fibers can be used for assembly of regular optical fiber bundles. The fibers from high purity glassy arsenic sulfide are suitable for operation in a spectral range from 1 up to 6.5 microns, the fibers on the basis of arsenic-selenide glasses and up to 11-12 microns in case of the fibers based on arsenic-selenide glasses.

By the method of drawing from a quartz double crucible having an output nozzle of square shape, the rectangular fibers having a core and reflecting cladding from arsenic-sulfide glass has been obtained. The side of the square fiber was from 250 up to 500 microns.

From such fibers the assemblies 8x8, containing 64 regularly located fibers, with length up to 15 cm were obtained. Then these assemblies were drawn into multi-core fibers with a length up to several tens of meters, with the size of a square equal to 250 microns.

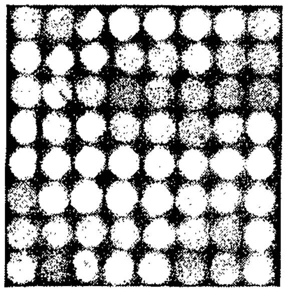

Fig. 7. A square shaped multi-core (8x8) fiber.

5. Mechanical strength of fibers made of arsenic-sulfide glasses

Strengths of the optical core-clad fibers were measured by the method of two-point bending between parallel plates, described in [4]. The results of measurement of strength of the optical fiber are represented in the form of Weibull plots showing the dependence of probability, F, of failure of the optical fibers upon the applied stress, σ. Measurements were carried out at room temperature. The velocity of the plate movement was 1 mm/s; the number of samples in each series of measurement was not less than 30; the fibre diameter was 400 mm. Fig. 8 shows a Weibull distribution plot for the fiber made of high-purity As-S glass (curve 3).

The stability of parameters of fibers at various conditions is of interest. The character of variations in a spectrum of the total optical losses was studied, numerical aperture and mechanical strength at bending of fibers with a core from $As_{40}S_{60}$ glass and reflecting cladding from $As_{39}S_{61}$ glass after action it by high-pressure.

The core diameter was equal to 300 microns, the thickness of reflecting cladding was 50 microns. The fiber had a protective polymeric coating from fluoroplastic F-42 with thickness of 10 mkm and secondary coating from PVC with thickness of 50 mkm. The fiber in the form of wheel rings was positioned in pressure gasostat. A pure argon was used as a working gas. The fibers were exposed to isostatic pressure equal to 85 and 40 MPa (850 and 400 at).

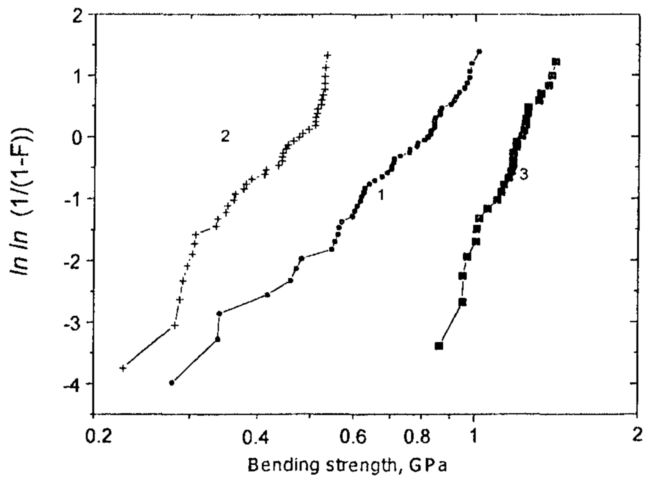

Fig. 8. Weibull distribution of bending strength of the fibers: diameter 400 microns with a primary coating from fluoroplastic F-42. Fibers on the basis of a glass: 1 is $As_{40}S_{30}Se_{30}$, 2 is $As_{40}Se_{60}$; 3 is $As_{40}S_{60}$.

Variations in value of numerical aperture before and after pressure treatment, with the error limit of measurements equal to 0.02, were not revealed.

The mechanical strength of fibers made of arsenic-sulfide glass subjected to high pressure treatment during one hour under pressure of 85 GPa decreased by 12 %. Weibull curve was biased

into an area of smaller strengths indicating influence of the same type of defects on mechanical strength of fibers before and after action of exterior isostatic pressure.

For two-layer fibers made of high purity As-S glasses, having a core from $As_{40}S_{60}$ glass and glass reflecting cladding from $As_{35}S_{65}$, slight variation of optical losses and bending strength due to pressure action was observed. These fibers had a primary polymeric coating from fluoroplastic F-42 with thickness of 10 microns and secondary polymeric coating from PVC with thickness of 100 microns. The common level of optical losses in such fibers within one year of storage at room temperature has increased on the average from 5 to 7 %, and the average bending strength was decreased on the average by 15 %.

6. Fibers made of high purity sulfoselenide glasses

The fibers from sulfoselenide glasses occupy an intermediate position between fibers from arsenic-sulfide and arsenic-selenide glasses both in a spectral range of optical transmission, and in values of bending strength.

It was shown in [5] that the multiphonon absorption edge for sulfoselenide glass shifts into long wavelength region in comparison with sulfide glass. At replacement of 30 at. % of sulfur for selenium in $As_{40}S_{60}$ glass the shift of a multiphonon absorption edge is about 1 micron and is considerably increased with the further increase of the selenium content.

The two-layer optical fibers on the basis of $As_2 S_{1.5}Se_{1.5}$ glass with a polymeric coating were obtained with the purpose of measurement their optical and mechanical characteristics. The glass of a core had a composition $As_{38}S_{25}Se_{37}$, and glass of a cladding was $As_{38}S_{27}Se_{35}$. For preparation of high purity sulfoselenide glass the direct melting of pure starting elements as well as the purification of sulfur and arsenic through monosulphide of arsenic were used. The two-layer optical fibers were drawn by the method of a double crucible with a ratio of diameters of a core and cladding (in microns) 300/400 and 200/400. The minimum losses measured by the double-point method, were equal to 190±20 dB/km at wavelength of 4.8 microns. In the 4-6 microns spectral range the optical losses were at the level of 200-300 dB/km. It is the best result in this area for the spectrum for two-layer fibers on the basis of chalcogenide glasses.

In Fig.9 the spectrum of the total optical losses in the fiber from As-S-Se glass with a ratio of diameters of a core and cladding of 300/400 and with a polymeric coatings is shown. In the spectrum of the fiber two spectral windows with the losses lower than 300 dB/km are visible: 3.2-4 microns and 4.4-6 microns. There are some peaks of absorption because of SH, CO_2 impurity at 4.31 and 4.34 microns; OH groups at 2.92 microns and traces of molecular water H_2O at 6.33 microns. The intensity of SH at 4.01 microns is 3 dB/m. The impurity band at 4.57 microns bound with absorption of SeH-group, is absent. For comparison the spectrum of the total optical losses for the fiber from As-S glass is given. From this figure the advantage of the fiber from As-S-Se glass is visible in the 5-6 microns spectral range in comparison with fibers from As-S glass. It is necessary to note that in the optical spectrum of fibers from As-S-Se there are no intensive absorption bands with maxima at 5.17 and 5.6 microns, which are characteristic of fibers from As_2S_3.

In Fig. 8 the Weibull distribution of bending strength of the fiber is submitted. The mean mechanical bending strength of the fiber is 0.8 GPa. The Weibull curve for sulfoselenide glass fiber occupies an intermediate position in relation to that for the arsenic-sulfide and arsenic-selenidefibers. The bending strength of a fiber from As-S-Se with fluoroplastic F-42 coating has decreased within 3 days from 0.8 GPa to 0.6 GPa, then there was stabilization, and the average bending strength remained invariable in time.

The effective numerical aperture of a fiber, determined by the angular distribution of output power, was equal to 0.28.

Through 1.5meter fiber with a diameter 400 microns six watts of continuous CO-laser radiation was transmitted. The input laser power was 12 watts.

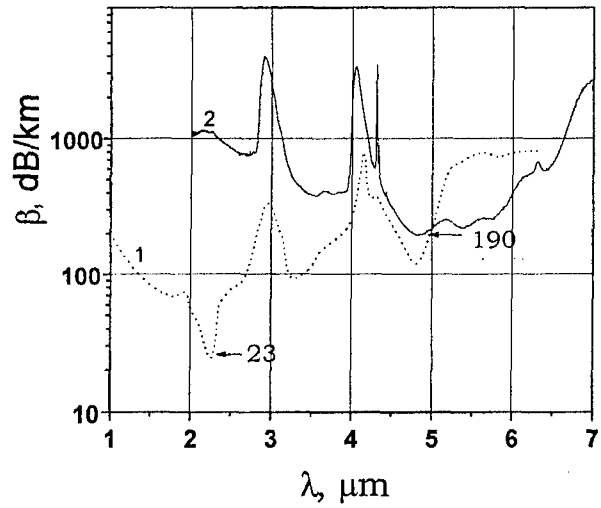

Fig. 9. Comparison of the total loss spectra of two-layer fibers from the glasses of As-S (1) and As-S-Se (2) systems.

The main parameters of arsenic sulfoselenide glass fibers are given in the table 2.

Table 2. Main parameters of optical fibers made of As-S-Se glasses.

Core/clad composition	Continuous length, m	$\varnothing_{clad}/\varnothing_{core}$ μm	A	β_{min} (dB/km) at λ(μm)	β (λ=5.5 μm), dB/km	Transmission of CO-laser radiation, W
$As_{38}S_{25}Se_{37}/As_{38}S_{27}Se_{35}$	>150	400/300 400/200	0.28	190 (4.8)	220	P_{in}=12 W P_{out} = 6 W

7. Fibers made of high purity arsenic-selenide glasses

As a material for manufacturing fibers for the spectrum range of a spectrum 2 - 11 microns the As-Se and Ge-As-Se glasses were used. The contents of germanium was up to 5 at. % (table 3). The fibers with a diameter from 300 up to 400 microns were drawn by the double crucible method.

In the last column the values of losses at λ = 10.6 microns wavelength are given. The intensity of absorption bands of OH - groups (λ=2.9 μm) in the spectra of optical losses of the best samples of fibers did not exceed 0.2 – 0.3 dB/m, molecular water (λ=6.3 μm) – 0.4 dB/m. The minimum optical loss in the unclad fibers made of As_2Se_3 glasses was equal to 76 dB/km at 4.3 μm, and 0.1-0.3 dB/m at 6.7 μm in case of As-Se-Te glass. The optical loss was equal to 3-4 dB/m at 10.6 mm in the best samples.

The average bending strength of two-layer fibers from Ge-As-Se glass with a fluoroplastic F-42 coating is 0.4 – 0.5 GPa and for best samples reaches 0.8 GPa.

Though the fibers on the base of arsenic-selenide glasses have the average bending strength twice smaller in comparison to fibers from arsenic-sulfide glasses, their main advantage consists in a wider range of spectral transmission. The long-wave edge of their transmission reaches10-11 microns, at optical losses in a fiber at a level of several dB/m.

Table 3. Compositions of core and cladding glasses of fibers from high purity arsenic-selenide glasses and the fiber's optical losses, dB/m.

Core glass composition	Clad glass composition	Optical loss, dB/m, at λ (*μm*)			
		2 ÷ 6	*6 ÷ 9*	*9 ÷ 11*	*10.6*
$As_{40}Se_{60}$	$As_{38}Se_{62}$	1 ÷ 1.5	1.5 ÷ 2.5	2.5 ÷ 11	11
$As_{39}Se_{61}$	$As_{36}Se_{64}$	0.3	0.3 ÷ 1.5	1.5 ÷ 8.5	8.4
$As_{38}Se_{62}$	$As_{34}Se_{66}$	0.3 ÷ 0.5	2 ÷ 5	2 ÷ 11	8.0
$Ge_1As_{39}Se_{60}$	$Ge_2As_{38}Se_{60}$	0.19	0.3 ÷ 0.8	0.8 ÷ 7	5.5
$Ge_2As_{38}Se_{60}$	$Ge_2As_{34}Se_{64}$	0.9 ÷ 2	2 ÷ 3	3 ÷ 7	5.0
$Ge_2As_{38}Se_{60}$	$Ge_4As_{36}Se_{60}$	0.2 ÷ 0.3	1 ÷ 1.6	1.6 ÷ 9	8.0
$Ge_2As_{38}Se_{60}$	$Ge_4As_{36}Se_{60}$	0.2 ÷ 0.6	0.6 ÷ 0.8	0.8 ÷ 6	3.0
$Ge_5As_{34}Se_{61}$	unclad	0.09 ÷ 0.3	0.3 ÷ 0.8	0.8 - 2.1	1.6

8. Application of IR fibers based on chalcogenide glasses

One of the most important directions of chalcogenide IR fibers use for the middle IR-range of 2 - 12 microns is concerned with the transmission of powerful laser radiation for the medical and technological purposes. For the radiation transmission of such lasers, such as the HF-laser (λ = 2.7 μm), YAG:Er3+-laser (λ =2.94 μm), DF-laser (λ = 3.8 μm), CO-laser (λ= 5.6 μm) and CO_2-laser (λ=10.6 a μm) IR-fibers are necessary. The level of optical losses in fibers, achieved by us, is given in the Table 4.

Table 4. Basic performances of the best fibers made of high purity glasses of As-S, As-Se and Ge-As-Se systems.

The characteristic of a fiber	Parameter
1. Minimum optical loss (dB/km) at wavelength	23 ($\lambda = 2.4\ \mu m$) (As-S) 79 ($\lambda = 4.3\ \mu m$) (As-Se)
2. Optical loss at laser wavelenghts, dB/km YAG:Er^{3+} (λ = 2.94 μm) CO- (λ = 5.5 - 6.3 μm) CO_2- (λ = 9.2 - 11.3 μm)	 160 100 - 200 1600
3. Intensity of impurity absorption bands OH SH	 60 800
4. The power of radiation transmitted through a fiber YAG:Er^{3+}-laser• CO-laser• CO_2-laser	 1.5 kJ/cm^2 10 W 1.5 W
5. Bending strength, GPa	0.5 – 1.2
6. Continuous fiber length	up to 100 m

•) The power, transmitted through a fiber, is limited to maximal output power of commercially available domestic lasers

The two-layer As-S glass fibers with the minimum contents of OH-groups and with the contents of microinclusions less than $2\cdot10^4$ cm^{-3} were used for the transmission of YAG:Er^{3+}-laser radiation. Through fibers with a diameter 460 microns which have loss about 250 dB/km at λ = 2.94

microns and length up to 1.5 m the pulses of YAG:Er^{3+}-laser with the duration of 350 μs and with density of power up to 1.5 kW/cm^2 were transmitted [6].

In [7] we describe a system for laser microsurgery of an eye lens, based on use of fiber from high purity arsenic-sulfide glass. The flexible multimode optical fibre with a diameter of 480 microns and length up to 3 m was used for the transmission of YAG:Er^{3+}-laser pulses (λ = 2.94 microns) with power at about 150 mJ and with frequency of 3 Hz. Through a fiber from $As_{35}S_{65}$ glass with a polymeric reflecting cladding with a diameter of 450 microns and length of 1.5 m it became possible to transmit within several hours the radiation of the continuous CO- laser (λ=5-6 mkm) with output power up to 10 W [8]. The power level of transmitting radiation was limited to parameters of the used laser. The optical losses in a fiber were about 700 dB/km at the wavelength of 5.5 microns. In [9,10] the possibility of chalcogenide IR-fibers use in optical pyrometry was shown. Small values of time constant of the described radiometers, and rather high accuracy allows to use them in high-speed scanning systems for the remote measurement of temperature under conditions of strong electromagnetic fields, aggressive mediums or for the supervision of temperature of hard-to-reach objects. The $Ge_5As_{38}Se_{57}$ glass fiber was used for radiation output of miniature cooled semiconductor lasers operating at the 6 - 10 mkm spectral region from a Dewar vacuum flask for the liquid helium storage [11]. The system of a cryostating of lasers with a radiation output through fiber has essentially improved the characteristics of IR-spectrometer for the molecular analysis of high purity volatile substances.

9. Conclusions

The fibers from high purity chalcogenide glasses have passed an initial stage of their development. To the present time the fibers with achieved optical losses and mechanical characteristics are quite satisfactory for their use in devices of new engineering. The main reasons causing the increase of optical losses of fibers and deterioration of their mechanical strength are investigated.

The improvement of the characteristics of IR-fibers from chalcogenide glasses is concerned with the further decrease of impurity level in chalcogenide glasses, improvement of fiber drawing procedures, development of methods of enlightenment and treatment of fiber and search for new strengthening coatings.

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